A Hybrid Ocean Wave Prediction Model - Combination of Single-Parameterized Wind Waves With Spectrally Treated Swells (複合海洋波予測モデル-単一パラメータの風波とスペクトル処理のうねりとの組合せ)

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論 文 内 容 要 旨

Based on macroscopic and dimensional considerations Toba (1972) proposed a power law relation (3/2 power law) between the nondimensional significant wave height H_s^* ($\equiv gH_S/u_*^2$) and nondimensional significant wave period T_s^* ($\equiv gT_S/u_*$) as $H_s^* = BT_s^{*3/2}$, with u_* as friction velocity and g as acceleration due to gravity. This relationship was consistent with the available empirical relations such as Wilson (1965) and of Mitsuyasu (1971), if the wind speed used in them is changed to friction velocity and then the fetch in them is eliminated. Field data support for the 3/2 power law was given by Kawai et al. (1977). Later, the validity of the above power law was found to be good also for the individual waves of the energy containing part of the wind wave spectrum (Tokuda & Toba, 1981). Based on the full use of the already recognized similarity structure in wind waves and on the above power law Toba (1972, 1974) proposed a spectral form for the high frequency side of the wind wave spectrum as :

$$\phi(f) = (2\pi)^{-3} \alpha_s g_* u_* f^{-4}$$

where α_s is constant and

$$g_* \equiv g \quad [1 + Sk^2/\rho_w g]$$

with S as surface tension and ρ_w as water density and again Toba (1978) had proposed a growth equation for the wind waves, as :

$$\frac{\partial E^{*2/3}}{\partial t^*} + \frac{E^{*1/3}}{a}\frac{\partial E^{*2/3}}{\partial F^*} = G_0R \quad [1 - \mathrm{erf}\,(bE^{*1/3})]$$

with $E^* \equiv g^2E/u_*^4$, $F^* \equiv gF/u_*^2$, $t^* \equiv gt/u_*$ and

where $a = 0.74$, $G_0R = 2.4 \times 10^{-4}$ and $b = 0.12$, which forms the basis of the present prediction model.

The above wave growth equation can predict the wind wave growth if a single character of the wind wave field, for example the total wave energy, alone is known. From the mutually transformable properties of the wind wave field which result from the similarity concepts, any other characteristics of the wave field can then be estimated. As the basic equation used in the present model predicts a representative character of the wind wave field, the present model also falls in the group of parametric models. Among the traditional and other recent parametric models based on the nonlinearity concepts, the present model has the advantage of the prediction of a single parameter for the complete description of the wave field whereas in the earlier parametric models, both the wave heights and periods are separately predicted (e. g. Wilson, 1965) and the predicted heights and periods have no relationship between them. In recent parametric models (Günther et al. , 1979) , five scale parameters are separately predicted. But, the single parameter treatment of the present model cannot be extended to swells due to the lack of similarity structure in swells and treatments based on spectral concepts are attached to the wind wave part, and thereby the present model has the hybrid character.

In the course of the development of the present hybrid model, a few transitional models using the same basic equation were also tried. Out of these transitional models, two of them are found to predict many features of the wave field with a few disadvantages. In the transitional model named as the wave packet following method or the first method (shown in Appendix) , a time series of wave prediction at a fixed point was not possible at certain times for the cases associated with some special nature of the wind field in the prediction region and also no wave energy spreading away from the wind direction was modeled. These defects arise due to the continued propagation of a wave packet from its newly attained position along the new wind direction until the packet reaches close to the prediction site and by the keeping of all the wave energy bound in the wind direction during the propagation of the wave packet. For the propagation of swells, the empirical form given in Bretschneider (1963) was used, which gives only the gross nature of the swells without any spectral decomposition. It also is not treating any momentum gain or loss depending on the wind field over the swells during their propagation.

In the next transitional model named as the grid model or the second model (shown in Appendix) , a time series prediction for any point in the prediction region is achieved by an interpolation of the wave energy to the grids at the end of each time step. This interpolation also provides spatial smoothing to the wind wave energy as energies at 4 points surrounding a particular grid are used in the spatial interpolation of the energy to the particular grid. Thus, two main defects of the first model are removed, but the swell field is again treated with the same empirical form used in the first model.

In the final model (hybrid model) , grid interpolation of wind wave energy along with a spectral treatment for swells is employed. In the new treatment of swells, a swell is divided into a number of frequency-directional components at the time of its formation at any grid. In giving energy to swell components at the time of its formation, the wind wave spectrum available at the grid of the swell formation is used. The swell components are then propagated through the prediction region with the group velocity decided by the linear wave theory, with growth or decay for each component, depending on the wind velocity. In representing a swell field at a grid, a nearly same procedure as in the transitional models is employed, that is, in the assignment of swell components to the nearest grid and in taking the maximum energy component among the swell components of the same frequency assigned to a grid. The interpolation of the swell energy to the grids, as done for the wind wave energy is not performed due to the few number of swell components, its random distribution and of the possibility of many directions of propagation of swell components.

The hybrid model was first tested in an ideal situation, that is, in a uniform wind field normal to a straight coast, and its accuracy was verified by comparing the results with the results from Wilson's (1965) empirical fetch graphs. A test to see the extent of smoothing occurring by the energy interpolation is performed and the results indicate that the maximum smoothing remains to be less than 22%. Then, the hybrid model's performance was tested through hindcasting ocean waves in several actual wind fields. The trial predictions included cases from simple spatially homogeneous winds to spatially and temporally varying winds of great intensity. These cases include predictions in very small scale area (Kii Channel Approach) where fine grids of the order of 500m and time steps of 5 minutes are used and that of large scale areas (N. Atlantic and N. W. Pacific ocean) where grids of 100km or more and time steps of 1 hour are employed. The results of the small scale case (which were calculated by the second model due to the lack of swell field in this case) showed good agreement with the wave measurements and the reasons behind a few noticed disagreements are explained and found to be not directly connected with the prediction scheme. In the Atlantic case, the results are compared with measurements and with other available model results. During most of the prediction duration good agreement of the predicted waveheights and wave spectra with their measured counterparts was found. The spatial distribution of the predicted significant heights also showed good agreement with the observed counterparts. In the Pacific case, the predicted results represented the spatial trends of the significant height distribution, but with lower predicted values. The lower predictions seem to be associated with the fixing of the numerical boundaries of this case and also with the visual ship observation's accuracy.

The tests in these actual wind fields clearly demonstrate the final model's ability in reproducing the spatial and temporal trends in wave development. The r. m. s. error in significant wave height for waves of heights up to 15m is found to be less than 1. 5m. The simple spectral form along with the spectral treatment of swells used in the final model was found to be sufficient in providing good spectral representation of the wave field.

Finally, few places in the model where modifications are needed for much better performances, are indicated with remedying minute alterations to the model. Such places include regions affected by numerical boundaries, regions influenced by localized features of the wind field and the regions in between wind belts having very large difference in wind speed. As the situations where modifications are to be assigned occur very rarely in practical prediction cases, the use of the hybrid model, as it is, is indicated for practical prediction purposes.

論文審査の結果の要旨

海面における波浪場の分布およびその変化は，大気海洋相互作用の重要な要素であって，その予測は大気・海洋の物理学固有の問題であるのみならず，さらに，船舶の安全航行や，沿岸の災害防止の基礎としても重要な課題である。

海洋波浪予測法は，大別してパラメータ法とスペクトル法に分けられる。1940 年代，風波を無次元の有義波高と有義波周期という二つのパラメータで表現して，経験則によりその発達を予測する方法がはじめて開発され，1950 年代には，海洋波をフーリエ成分に分解してそのスペクトル成分ごとの発達を予測する方法の研究が進んできた。しかし，1960 年代以後研究されてきた成分波間の非線形相互作用が極めて複雑であるうえに，風の作用による風波へのエネルギーインプットの力学がまだ解明できないため，スペクトル法は十分合理的な形に到達していない。

いっぽう，おそらくは風の作用による波面の局所的な流れや，それによる乱れの効果を含む，波の間の複雑な非線形相互作用のために，実際上風波の場に著しい自己相似構造が存在する。その最も単純な表示は，風波の無次元の波高と周期の間の 3 / 2 乗則およびエネルギースペクトルにおける周波数の－ 4 乗則と，それに基く発達方程式である。これらは 1970 年代に鳥羽により提唱されていたものであるがジョセフＳ.パイムピリルは，これをもとに，実際の変化する風の場に対して，風波の場とその変化を追跡する実用的な風波予測モデルを開発した。

また，風波は，風の方向変化や風速の弱まりにより，うねりを生ずる。またうねりは，風が強くなると風波に変わる。この風波とうねりの転換部をも適切なやり方でモデル化した。

さらに，種々の基礎テストに加えて，小スケールの紀伊水道，大スケールの大西洋，および日本近海の太平洋において，風と波浪との観測資料の入手できる場合について，事後予測によるテストを行ない，このモデルが十分実際的に有効であることを示した。

なお，このモデルは論文提出直後国際的な波浪予測モデル相互比較研究のワークショップにおいて，十分の評価を得ている。

以上のように，この研究は海洋波浪予測モデルに関して新しい境地を開いたもので，申請者が自立して研究を行うに必要な高度の研究能力と学識を有することを示している。

よってジョセフＳ.パイムピリル提出の論文は，理学博士の学位論文として合格と認める。